MODIS TEB Calibration and Performance

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Outline

- MODIS TEB and on-orbit calibration
- TEB calibration performance
- TEB C7 algorithm improvements
- Summary

TEB Design Specifications

Band	CW	Ttyp	NEdT	UC (%)	UC (K)	Primary Use
20	3.75	300	0.05	0.75	0.18	Surface/cloud temperature
21	3.96	335	0.20	1	2.97	
22	3.96	300	0.07	1	0.25	
23	4.05	300	0.07	1	0.25	
24	4.47	250	0.25	1	0.19	Atmosphere temperature
25	4.52	275	0.25	1	0.24	
27	6.72	240	0.25	1	0.27	Water vapor
28	7.33	250	0.25	1	0.32	
29	8.55	300	0.05	1	0.53	Cloud properties
30	9.73	250	0.25	1	0.42	Ozone
31	11.03	300	0.05	0.5	0.34	Surface/cloud temperature
32	12.02	300	0.05	0.5	0.37	
33	13.34	260	0.25	1	0.62	Cloud top altitude
34	13.64	250	0.25	1	0.59	
35	13.94	240	0.25	1	0.55	
36	14.24	220	0.35	1	0.47	

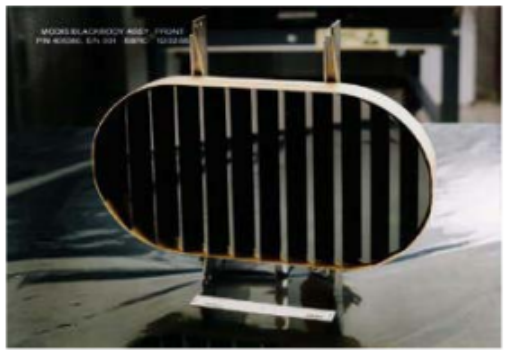
CW: center wavelength in micron;
Ttyp: typical scene temperature in K;
NEdT: noise equivalent temperature difference in K

On-orbit Calibration Methodologies

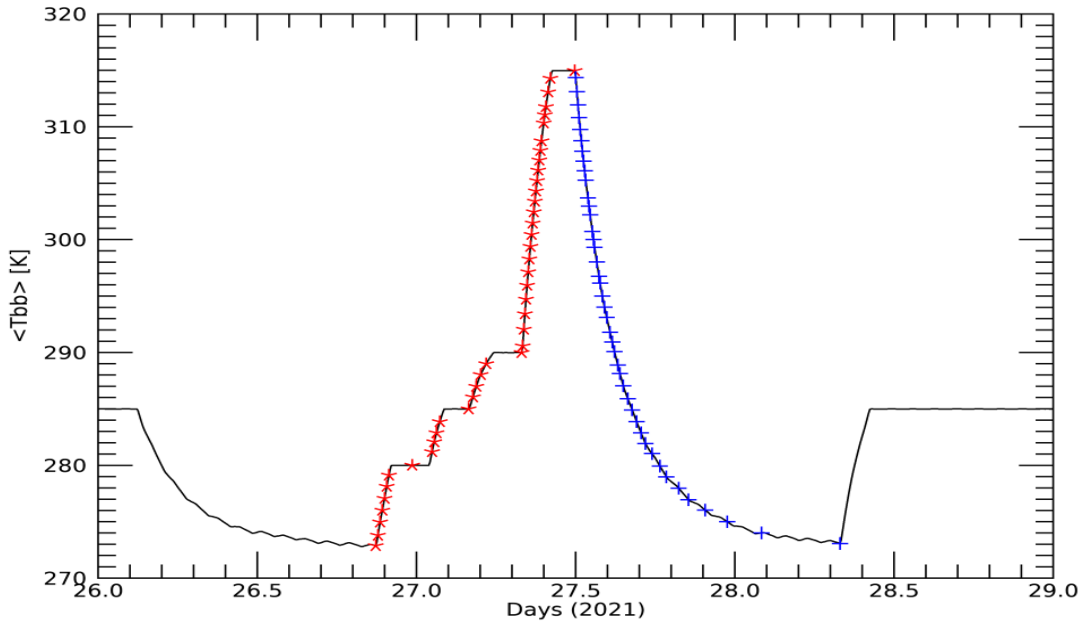
EV Radiance: $$L_{EV} = \frac{1}{RVS_{EV}}\left(a_0 + b_1 \cdot dn_{EV} + a_2 \cdot dn_{EV}^2 - \left(RVS_{SV} - RVS_{EV}\right) \cdot L_{SM}\right)$$

Calibration Coefficients:

$$b_1 = \left(RVS_{BB} \cdot \varepsilon_{BB} \cdot L_{BB} + \left(RVS_{SV} - RVS_{BB}\right) \cdot L_{SM} + RVS_{BB} \cdot \left(1 - \varepsilon_{BB}\right) \cdot \varepsilon_{cav} \cdot L_{cav} - a_0 - a_2 \cdot dn_{BB}^2\right) / dn_{BB}$$



Aqua WUCD 2021026



RVS: response versus scan-angle
e: emissivity
L: spectral band integrated radiance
dn: digital count with background corrected
a0 & a2: non-linear gain coefficients
b1: linear gain coefficient

WUCD T_{BB}: ~270 K to 315 K

On-orbit Calibration Methodologies

- **Regular BB Calibration**
  - Compute linear gain coefficient b1 on a scan-by-scan basis
  - 40-scan running average used in the L1B product
- **Quarterly BB Warm-up and Cool-down (WUCD) Activities**
  - Compute nonlinear gain coefficients a0 and a2
  - Derive fixed linear coefficients for band 21
  - Aqua default b1 for bands 33, 35 and 36
- **Special Calibration Issues**
  - Characterization of response versus scan angle
  - Aqua CFPA temperature fluctuation
  - Terra PV LWIR bands 27-30 electronic crosstalk
  - Terra PC bands 32-36 optical cross-talk
  - Uncertainty
  - QA
- **Calibration Assessments and Monitoring**
  - Gain trending, NEdT trending, Ecal and saturation monitoring
  - EV scene (Dome-C, Ocean, DCC/qDCC)
  - Inter-comparisons with IASI and CrIS, Terra - Aqua, and MODIS - VIIRS.

MODIS TEB Performance

- **Terra MODIS TEB**

  -- Overall performance is stable.

  -- PV LWIR bands 27-30 electronic cross-talk has been corrected for calibration and EV measurement.

  -- BB temperature was changed from 290K to 285K after April 23 to April 25, 2020 WUCD.

  -- NEdT and uncertainty meet specifications, except band 36.

  -- One more noisy detector since last STM (band 28 detector 1)

  (https://mcst.gsfc.nasa.gov/calibration/time-dependent-list-non-functional-or-noisy-detector,)

- **Aqua MODIS TEB**

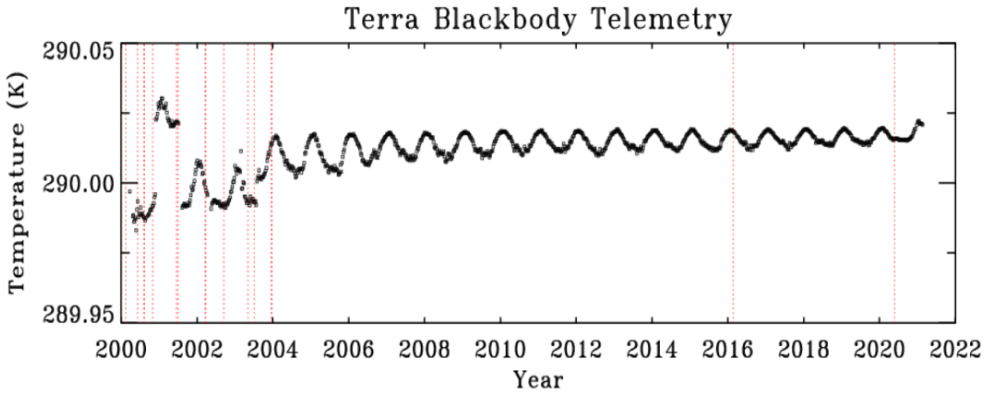
  -- Overall performance is stable.

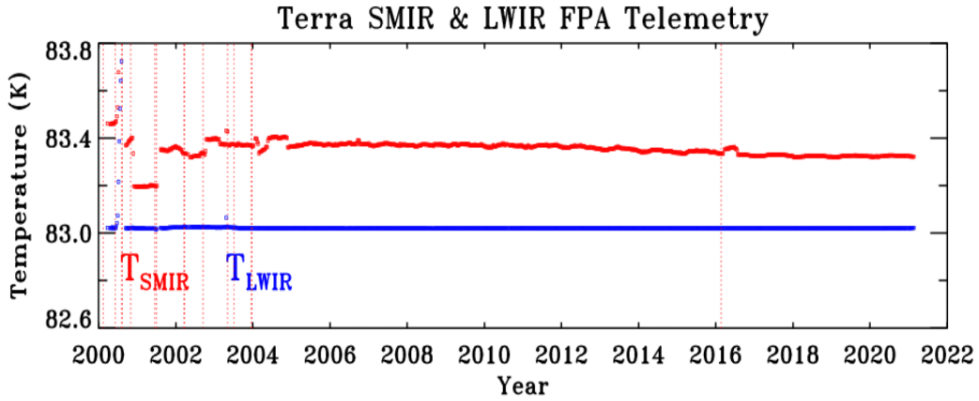
  -- NEdT and uncertainty meet specifications.

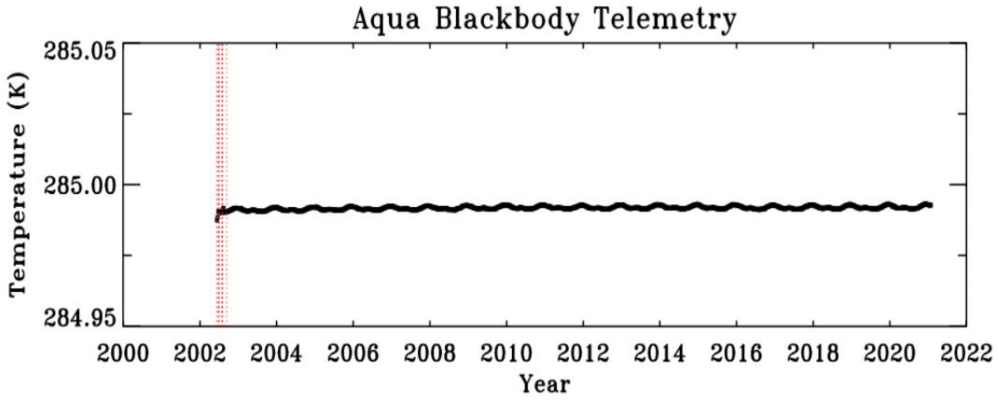
  -- Increase of CFPA radiative cooler margin and CFPA temperature control improved since 2013.

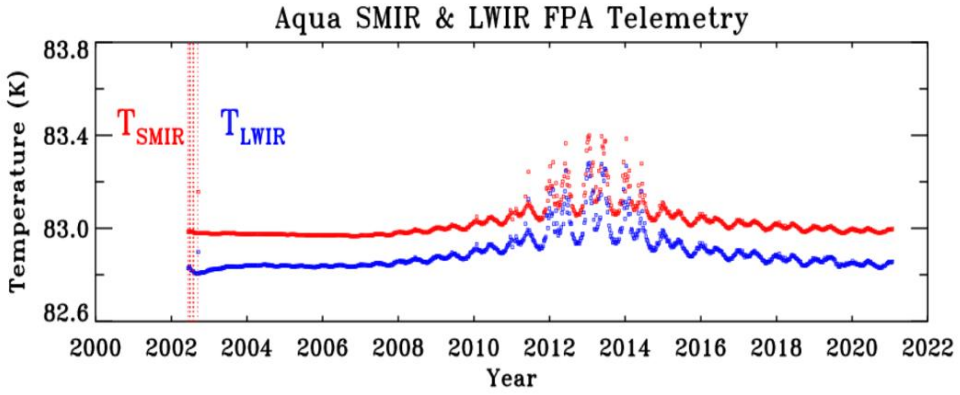
  -- No noisy detector added since last STM

Key Telemetry Temperatures



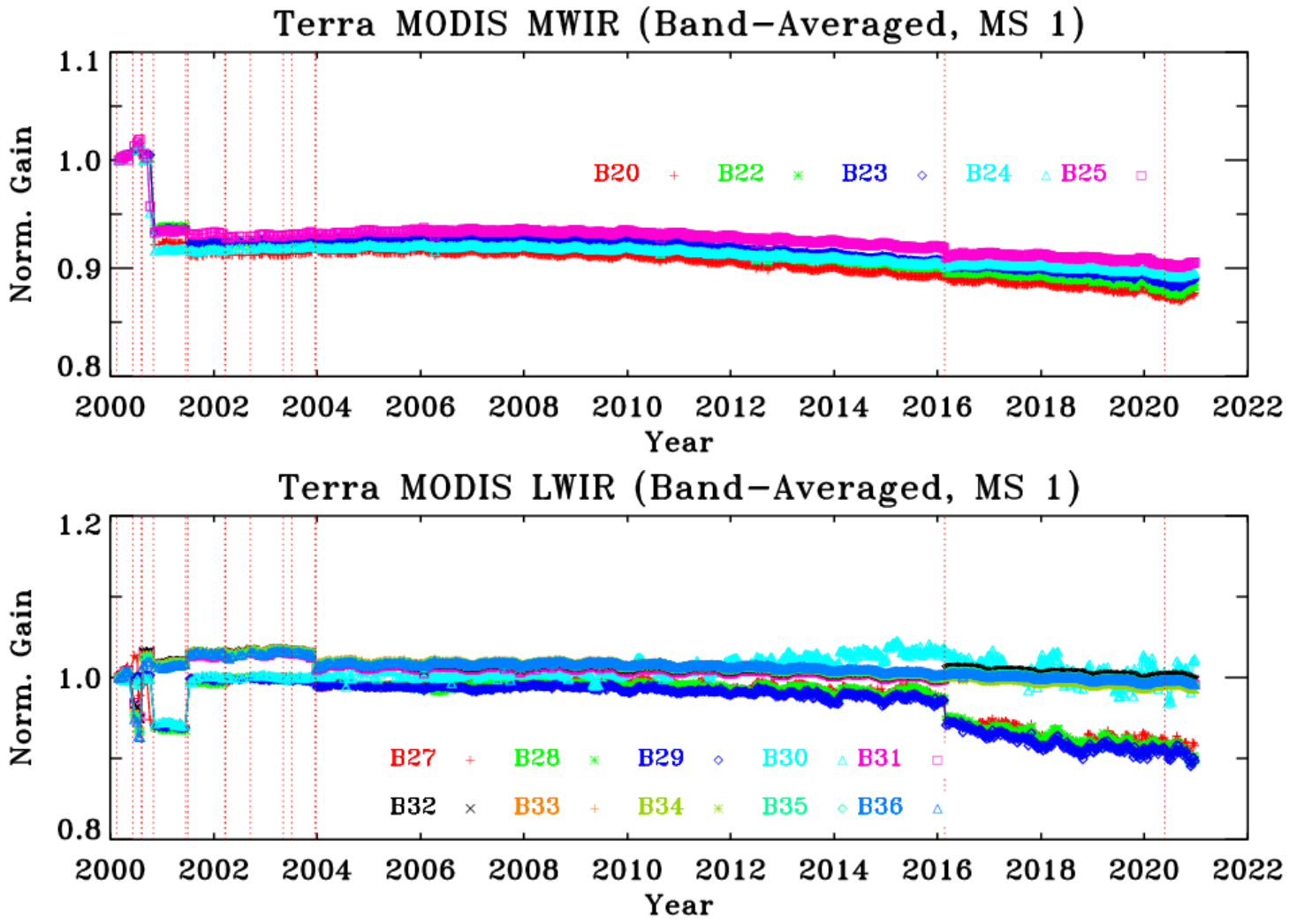






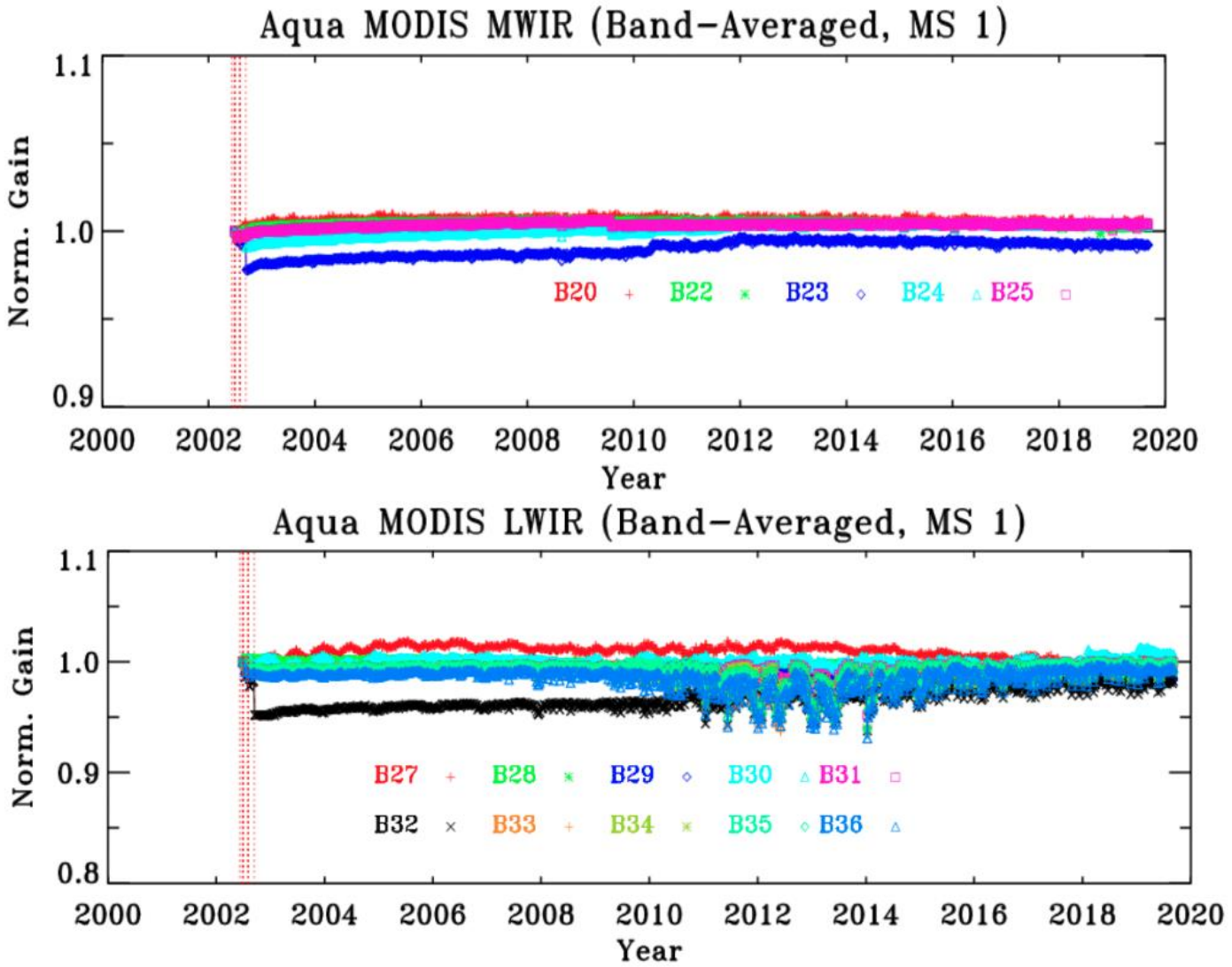
- In the Terra BB temperature trending plot, the temperature is shifted 5K for matching the temperature trending. No impact on the CFPA temperature.
- Aqua SMIR CFPA actively controlled (83K), insufficient radiative cooler margin starting ~2006
  -- Increase of radiative cooler margin and improvement of temperature control since 2013

Terra TEB Gain Trending



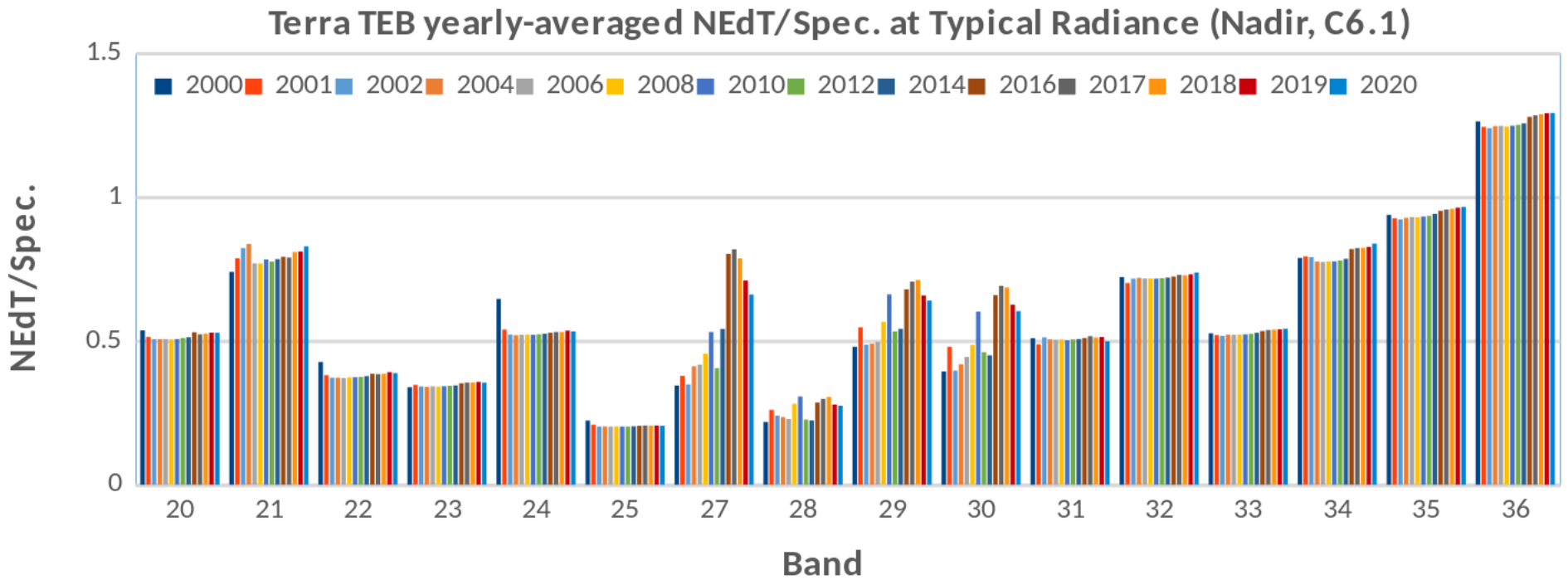
- Before 2004, the gain changes are due to configuration changes.
- Safe mode event of Feb 2016 caused gain changes for some bands, especially for PV LWIR bands.
- No impact from the BB temperature 290-285K change

Aqua TEB Gain Trending



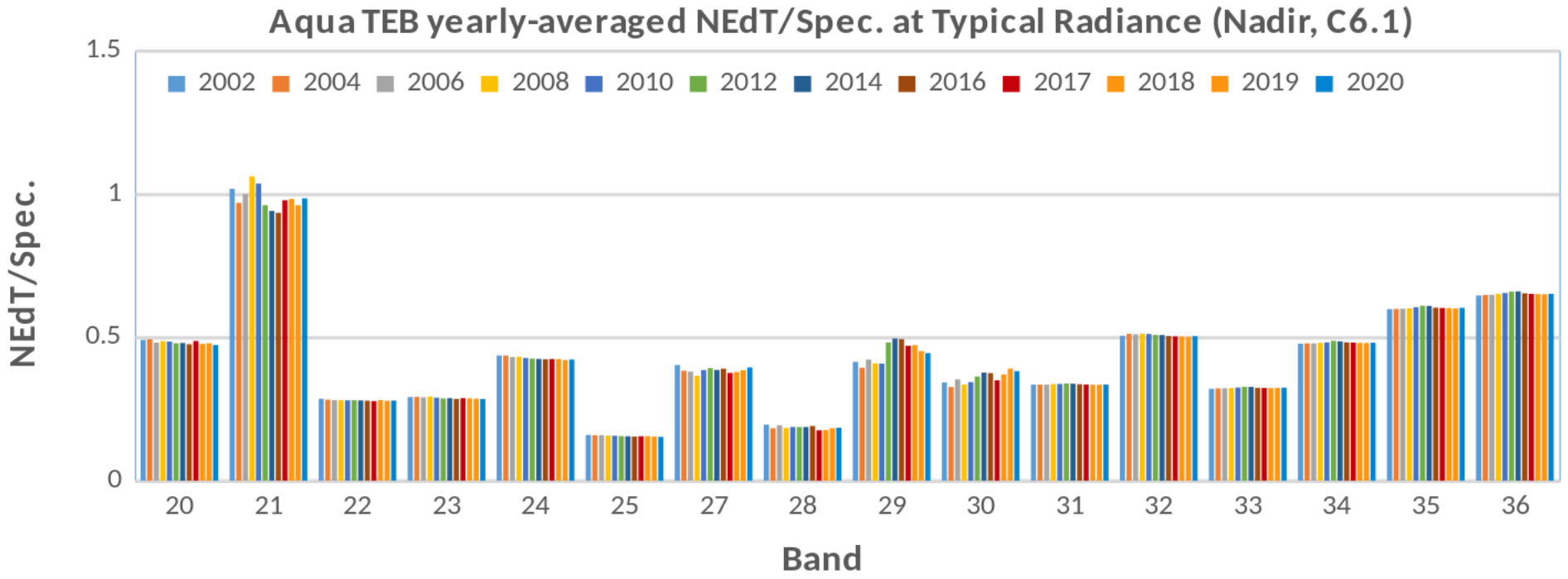
- MWIR bands are stable over the mission
- CFPA temperature impacts on gain for LWIR bands.

Terra TEB NEdT Trending



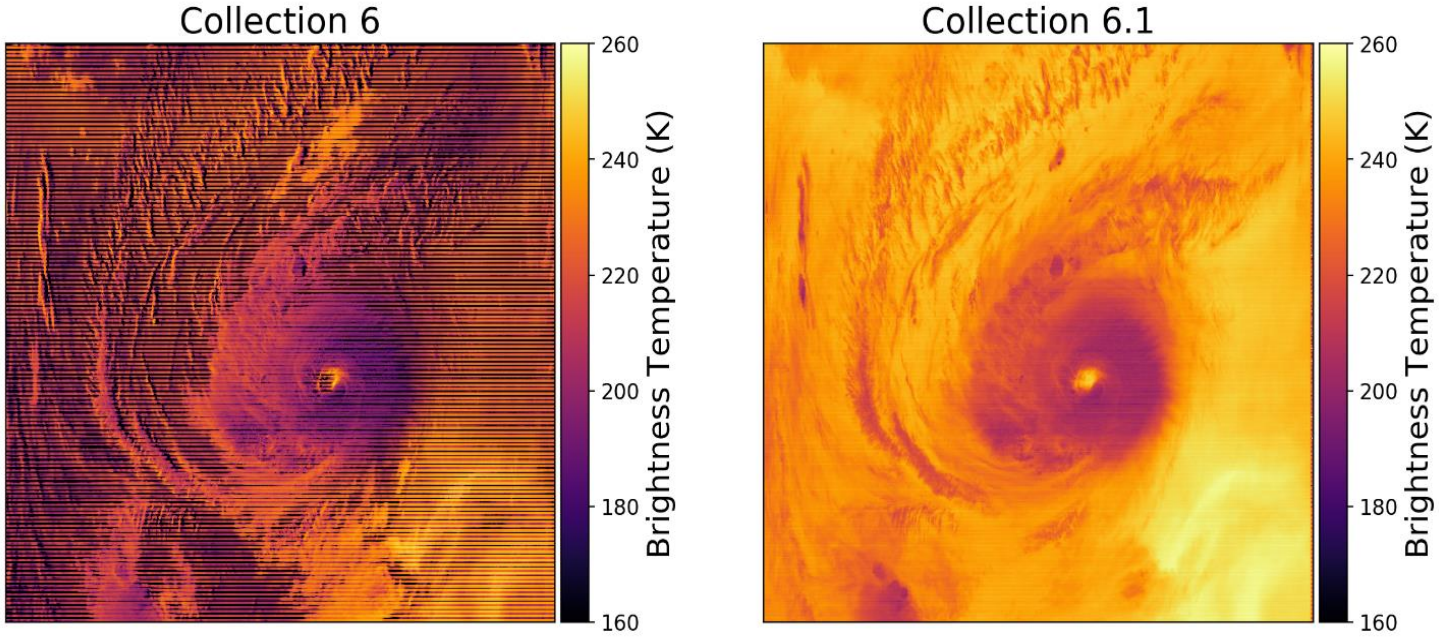
- Safe mode event of Feb 2016 caused NEdT changes for some bands, especially for PV LWIR bands.
- No impact from the BB temperature 290-285K change
- Band 36 NEdT is above the specification

Aqua TEB NEdT Trending



- NEdT meets the specification and stable over the mission
- Band 21 NEdT is close to the specification and overall meet the specification.

MODIS TEB electronic cross-talk corrections

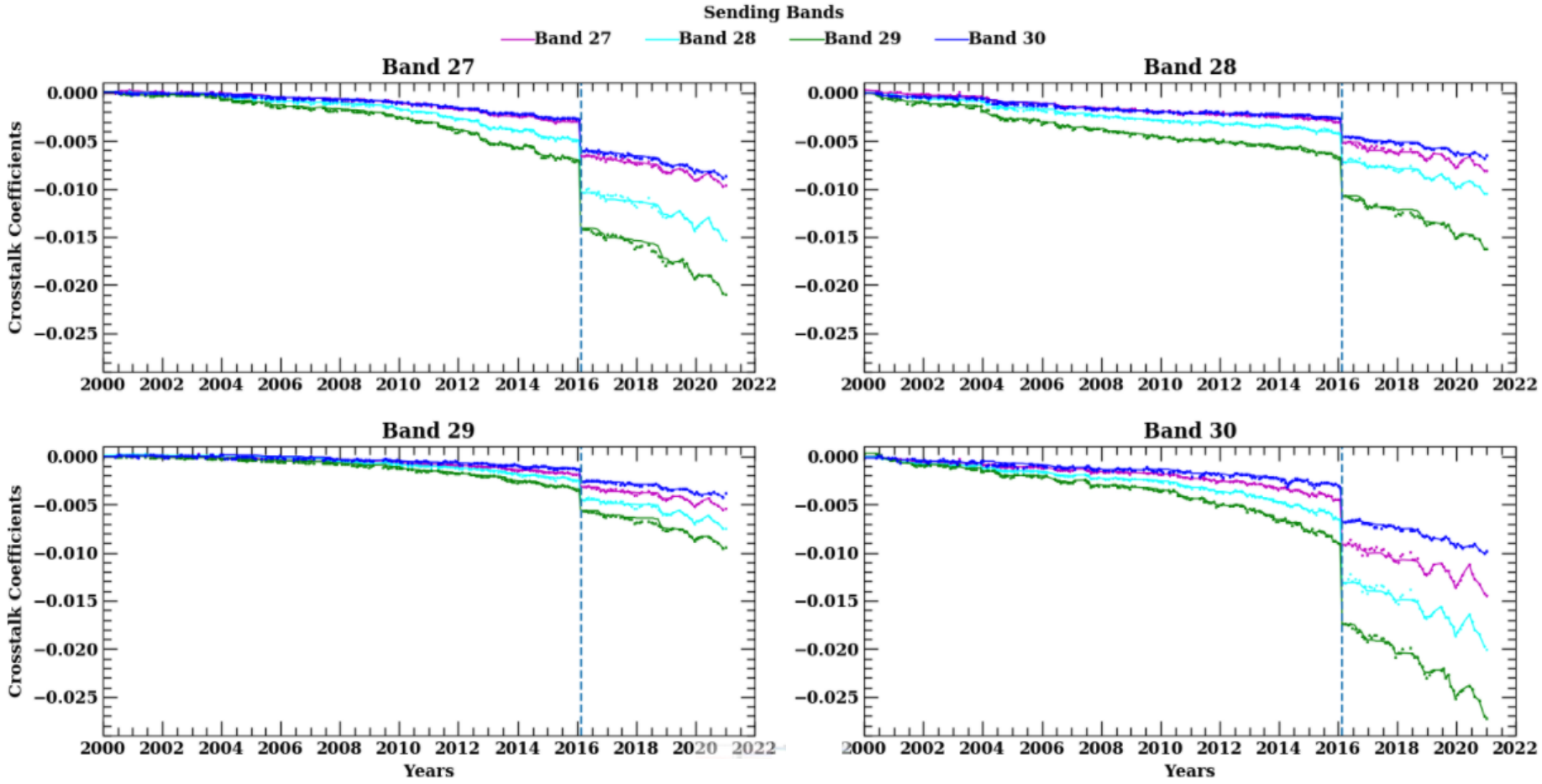


Example image correction for band 27 of Terra MODIS on August 27, 2020.
The image shows Hurricane Laura making landfall on the Gulf coast.

- Cross-talk corrections have been implemented in C6.1 for Terra PV LWIR bands 27-30.
- Corrections for selected detectors of Terra MWIR, Aqua MWIR and LWIR are recommended for future calibration improvement.

https://mcst.gsfc.nasa.gov/sites/default/files/meetings_files/2018_mcst_xtalk_workshop.pdf.

Terra PV LWIR Bands Cross-talk



- These plots are sending band averaged coefficients
- Dots are coefficients from scheduled lunar observation and the lines are the LUT coefficients
- Safe mode (Feb 2016) caused the jump of the cross-talk. Increased effects of crosstalk after safe mode

MODIS TEB C7 algorithm improvements

Terra

(1) MWIR bands cross-talk correction for selected detectors

(2) Band 30 algorithm change to improve stability

(3) Bands 20 and 29 a0 correction and a2 re-processing for cold scene bias correction

(4) Early mission PC bands a0 correction for mirror side difference correction

Aqua

(1) MWIR and LWIR bands cross-talk correction for selected detectors

(2) Entire mission a0 correction and a2 re-processing for mirror side difference correction

Detailed analysis and test results were presented on May 13, 2020 at MSWG and November 18, 2020 meetings.
https://mcst.gsfc.nasa.gov/sites/default/files/file_attachments/M1163.pdf

Terra MWIR bands cross-talk corrections

- A correction was applied to the Terra PV LWIR bands 27-30 in Collection 6.1. The mid-wave infrared bands in Terra MODIS, 20 – 25, also show noticeable electronic cross-talk contamination for selected detectors. The impact can be seen during Moon observations, along with some striping in the Earth images.
- A cross-talk correction for selected detectors of the Terra MWIR bands will be applied in C7.
- The selection of the detector for correction depends on the impact on L1B product and image quality.
- The cross-talk coefficients have been processed for entire mission. The crosstalk are stable and show a slight downward trend for some detectors.

Band	Detector	Contamination Impact
22	8	Large striping over ice cloud scenes and water scenes (~0.5K).
23	1,10	Large striping over ice cloud scenes and water scenes (~0.5K).
24	1	Striping over ice cloud scenes and 0.5 -1 K change over ocean scenes

Reference:
(1) Wilson, T., A. Shrestha, and X. Xiong, "Electronic crosstalk impact assessment in the Terra MODIS midwave infrared bands", Proceedings Volume 10423, Sensors, Systems, and Next-Generation Satellites XXI; 104231Z, 2017
(2) https://mcst.gsfc.nasa.gov/sites/default/files/meetings_files/2018_mcst_xtalk_workshop.pdf.

Aqua MWIR and LWIR bands cross-talk corrections

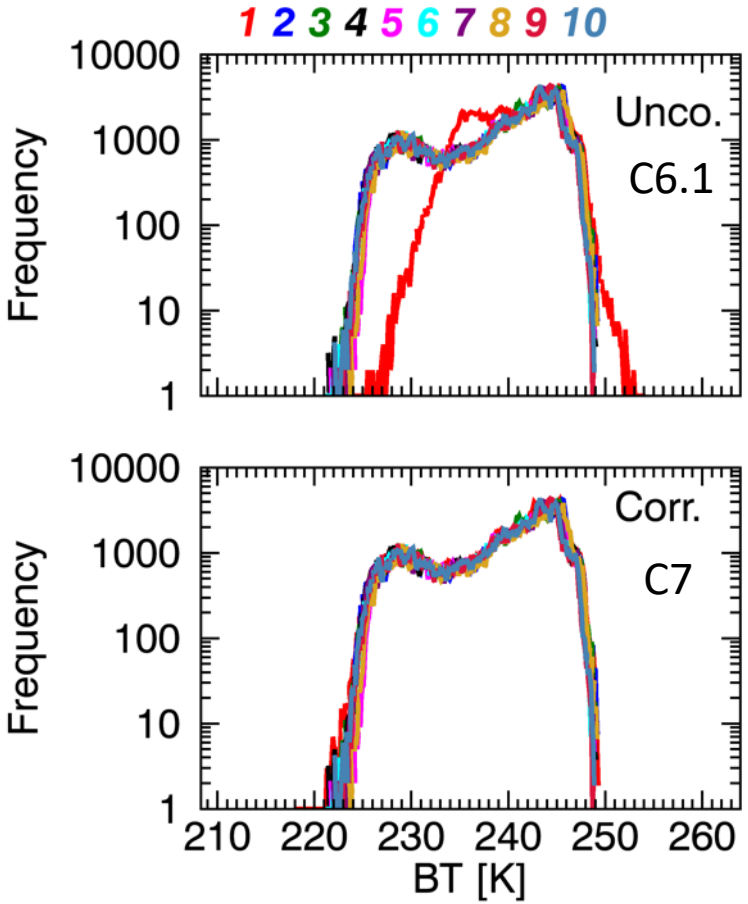
- Electronic cross-talk contamination can also be seen in lunar images. Striping can be observed in the Earth images.
- A cross-talk correction for selected detectors of the Aqua MWIR and LWIR bands will be applied in C7.
- The selection of the detector for correction depends on the impact on L1B product and image quality.
- Mission-long cross-talk coefficients have been processed for the Aqua MWIR and LWIR bands.
- The cross-talk coefficients are stable and a slight downward trend for some detectors.

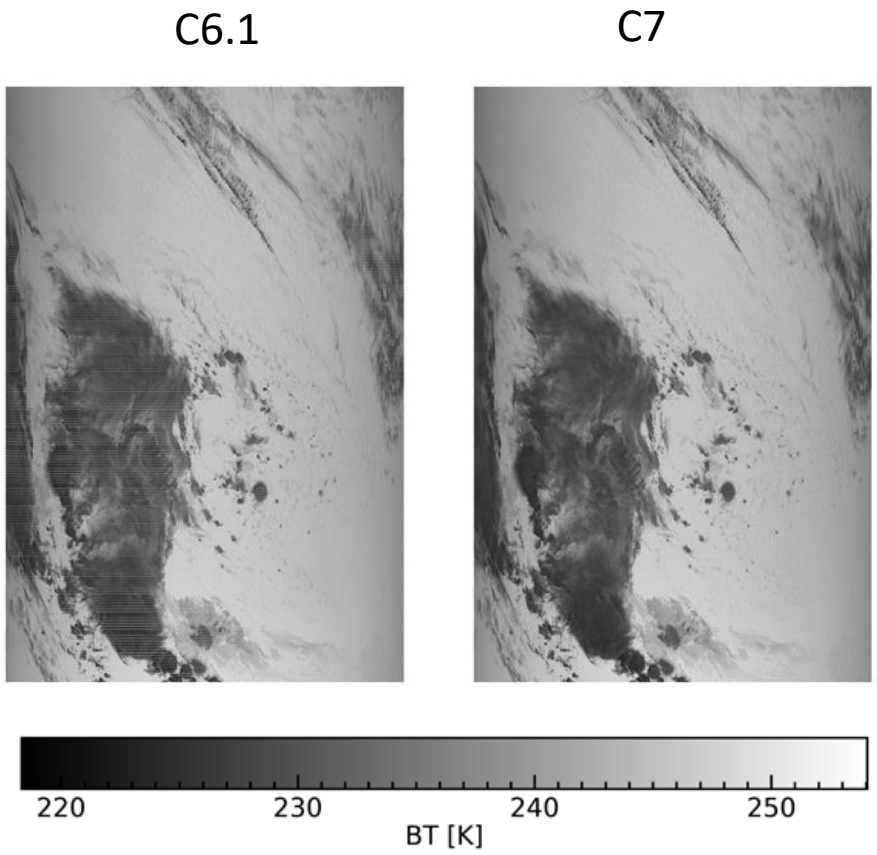
Band	Detector	Contamination Impact
20	1	Striping over some scenes (~0.15K).
22	1	Striping over some scenes (~0.20K).
23	1	Large striping over ice cloud scenes and water scenes (~0.5K).
24	1	Striping over low BT scenes during daytime.
25	1	Striping over some scenes (~0.20K).
27	1	Large striping over some scenes (~0.80K).
29	1,2,6	Striping over some scenes (~0.3K).
30	1	Striping over some scenes (~0.45K).

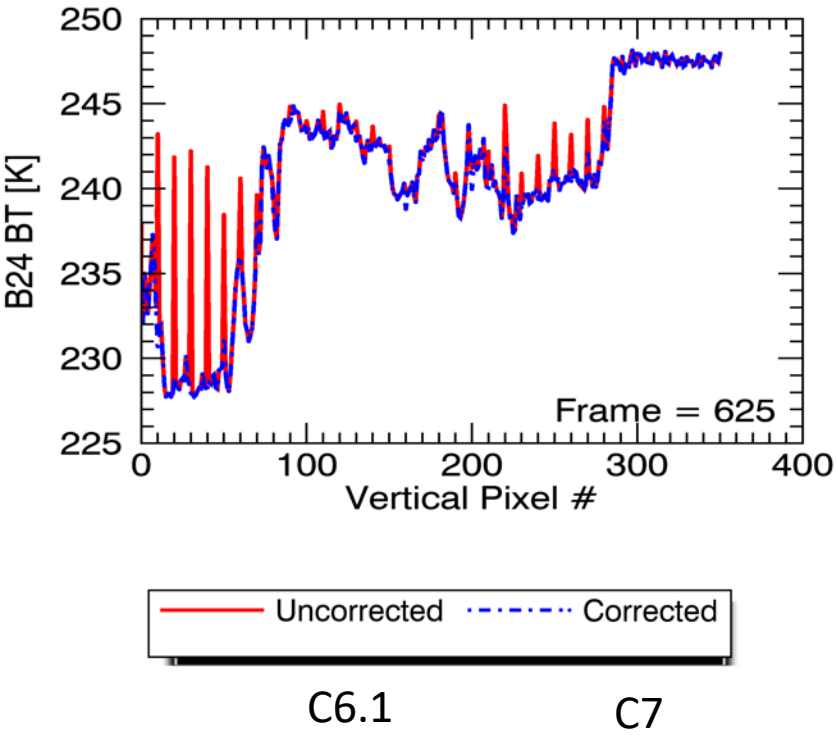
Reference: https://mcst.gsfc.nasa.gov/sites/default/files/meetings_files/2018_mcst_xtalk_workshop.pdf.

Aqua band 24 cross-talk correction

The cross-talk correction has been tested for multiple granules. The L1B data changes are as expected. Band 24 detector 1 displays the largest image striping impact for cold scenes. The striping is greatly reduced after correction. Histograms show detector back in-family after correction.

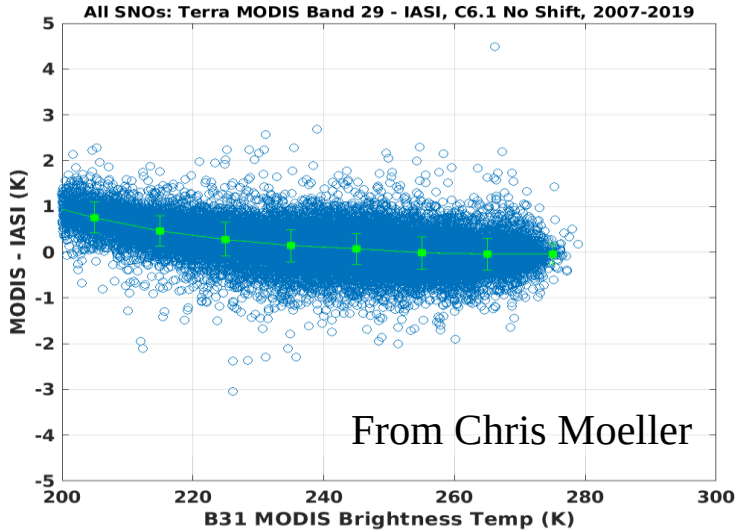


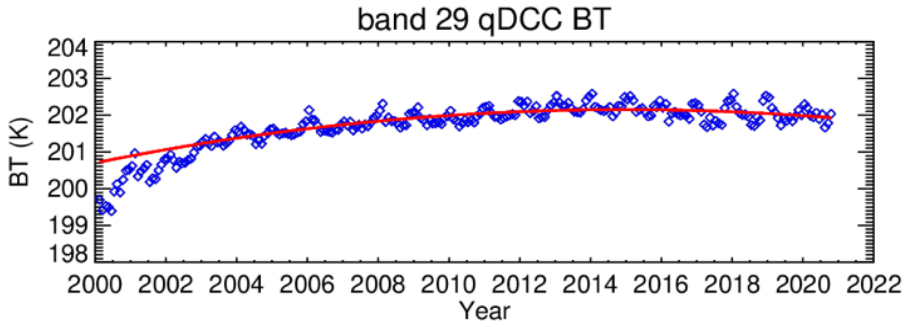


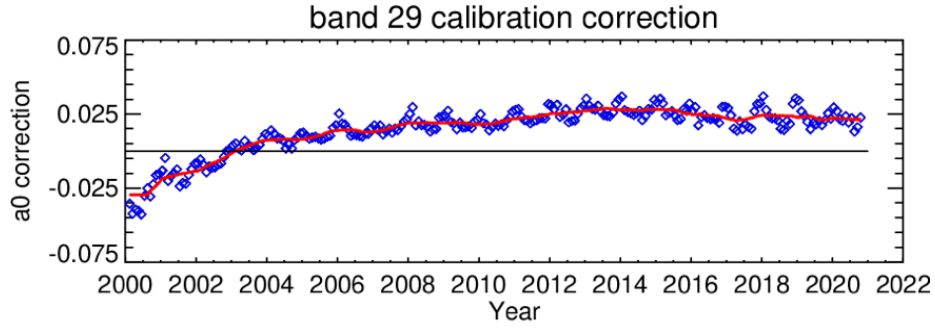


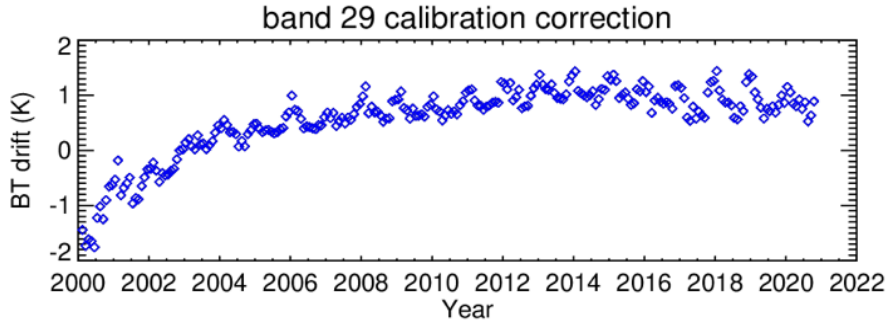
Terra Bands 20 and 29 a0 correction and C7 algorithm

- Terra-IASI comparison (is from 2007 to 2019) shows BT-dependent bias. Lower BT scenes show larger biases.
- The trending from qDCC (~200K) analyzed for bands 20 and 29 for entire mission.
- The BT bias and drift over qDCC, derived combining Terra-IASI comparison and qDCC trending, are used for a0 correction
- For each WUCD event, apply the a0 correction for both mirror sides and derive a2.





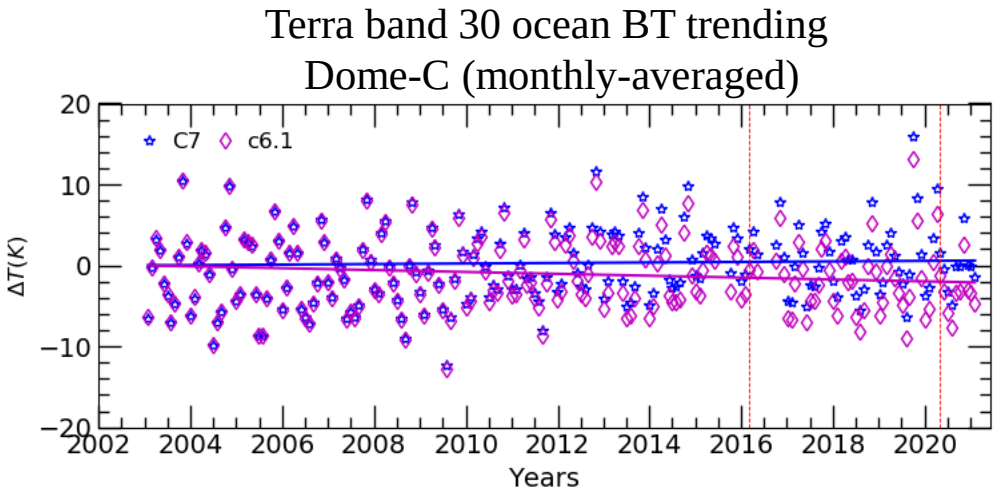


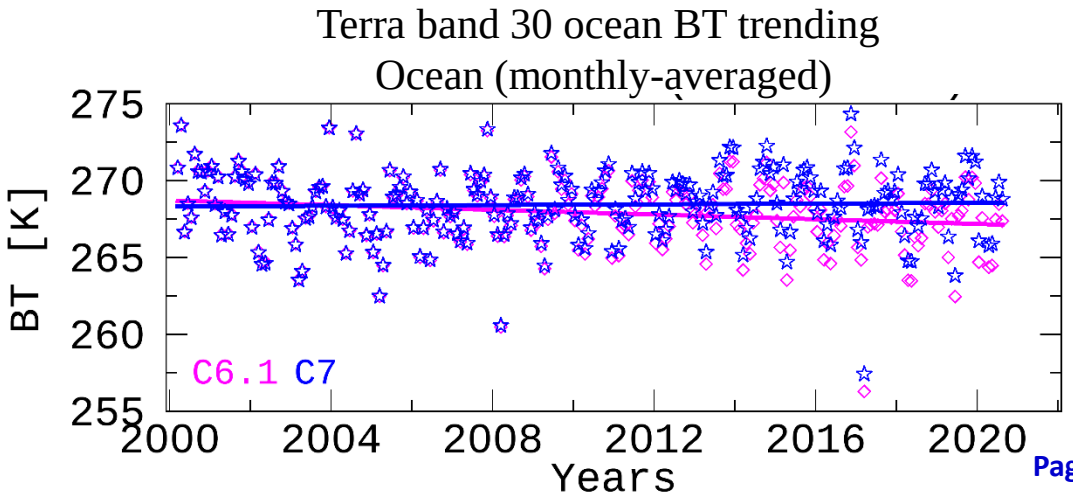


Reference: Chang, T., X. Xiong, A. Shrestha, and P. C. Diaz, "Methodology development for calibration assessment using quasi-deep convective clouds with application to Aqua MODIS TEB", Earth and Space Science, vol. 7, issue 1, pp. 1-15, 2020.

Terra band 30 C7 algorithm

- C6.1 band 30 shows downward trending from Terra-IASI time series (2007-2019).
- Earth view trending results over Dome-C (cold scene), qDCC, and the ocean (warm scene) also exhibit these biases (decreasing trend). This bias is larger for low BT scenes.
- For C7, use a0 and a2 from 2003 LUT (after last configuration change) to re-process Terra MODIS band 30 for entire mission
- For both the Dome-C site and an ocean location in the Bahamas, one month's worth of EV data for every year of the Terra MODIS mission was re-processed using the a0 and a2 calibration coefficients from C7 LUT
- Comparison tests between this trial and C6.1 demonstrate significant bias corrections for both the Dome-C (cold) and ocean (warm) Earth scenes





Summary

- Overall performance is stable for both Terra and Aqua MODIS TEB
- Terra BB temperature was changed to 285K after April 23 to April 25, 2020 WUCD.
  -- The instrument performance is as expected. No impact on noise performance (NEdT).
  -- No noticeable impact on calibration coefficients and on EV L1B products.
- Since last STM, one noisy detector added to Terra and no noisy detector add for Aqua.
- Increase of Aqua CFPA temperature control since 2013.
- In C7, the crosstalk correction will be applied for selected detectors for Aqua PV bands and for Terra MWIR bands.
- C7 calibration algorithm improvement for Terra bands 20, 29, and 30 to improve stability.
- C7 calibration algorithm improvement for Aqua TEB a0a2 to improve mirror side consistence.

Backup

Terra BB temperature change

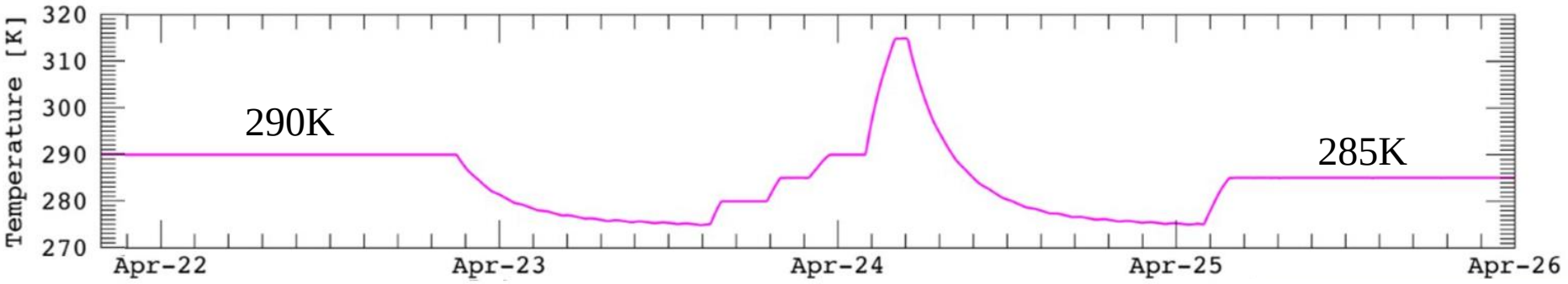
- Terra BB temperature was changed to 285K after April 23 to April 25 WUCD (April 25 02:00)
- The instrument telemetry temperatures, instrument response, and impact on Earth L1B measurements are monitored and analyzed.

✓ The instrument performance is as expected. The instrument temperatures decrease slightly and CFPA temperature is stable.

✓ Calibration coefficients change is insignificant. Mini-L1B, Semi-L1B, and analytical modeling show negligible impact on L1B product

✓ No impact on instrument Noise performance (NEdT)

✓ No significant change in EV BT (Dome-C, Ocean, and Terra-IASI comparison, no change were observed above the noise and method uncertainties).



Collection 6.1 TEB QA Table

Terra

B/d	1	2	3	4	5	6	7	8	9	10
20										
21										
22										
23										
24										
25										
27										
28										
29										
30										
31										
32										
33										
34										
35										
36										

Aqua

B/d	1	2	3	4	5	6	7	8	9	10
20										
21										
22										
23										
24										
25										
27										
28										
29										
30										
31										
32										
33										
34										
35										
36										

- **Current QA table**
- **Terra band 28 detector 1 added**
- **Product order**

noisy

inoperable

MODIS TEB C6.1 and C7 algorithms comparison

MODIS TEB C6.1 calibration algorithm

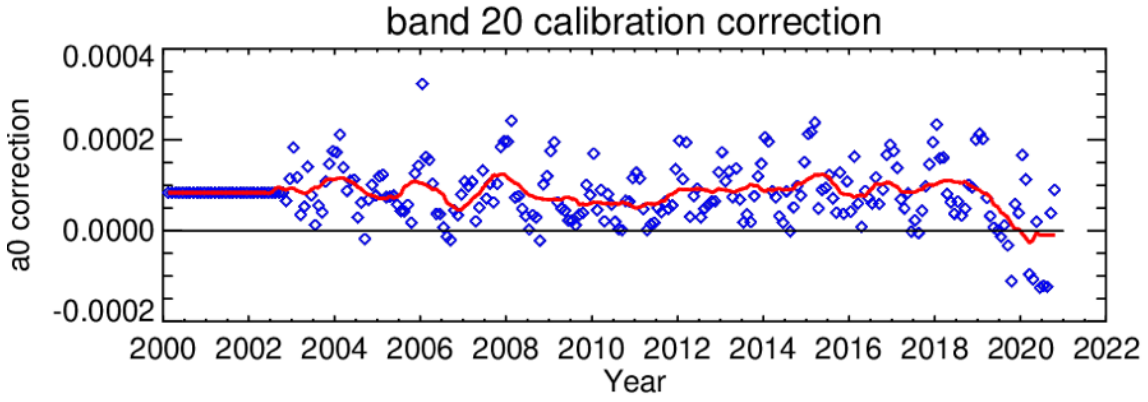
Band	Aqua	Terra	
	Calibration algorithm	Calibration algorithm	Cross-talk correction
20	PL a_0 PL adjusted CD a_2 (CD: cooldown).	$a_{0\_ms1} = 0$ $a_{0\_ms2} = a_{0\_ms2}^{\text{free-fit}} - a_{0\_ms1}^{\text{free-fit}}$ CD a_2	
22			
23			
24			
25			
27			PV LWIR electronic cross-talk
28			
29			
30			
31	a_0=0, CD a_2	$a_0 = 0$ CD a_2	
32			PC LWIR optical cross-talk
33	a_0=0 PL adjusted CD a_2		
34			
35			
36			

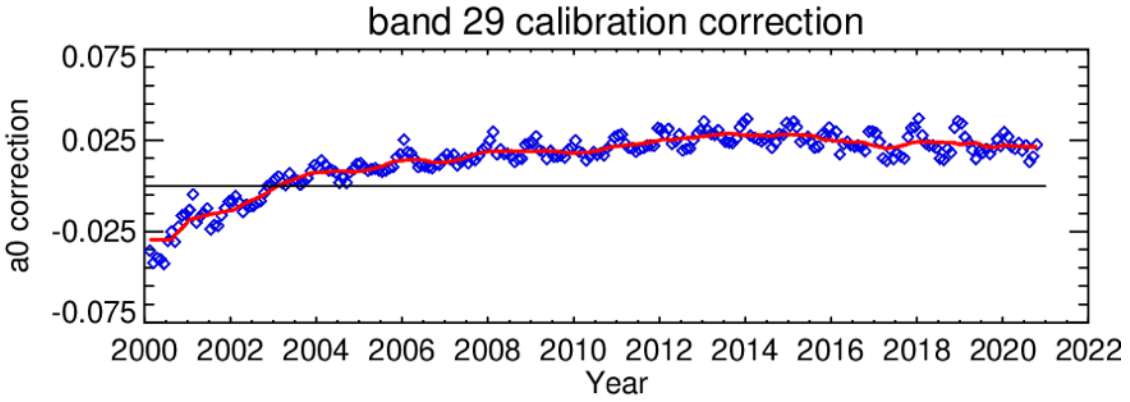
MODIS TEB recommended C7 calibration algorithm

Band	Aqua		Terra	
	Calibration algorithm	Cross-talk correction	Calibration algorithm	Cross-talk correction
20	PL a_0 with MS correction CD a_2	Electronic cross-talk corrections for selected detectors	Corrected a_0; CD a_2	Electronic cross-talk corrections for selected detectors
22			$a_{0\_ms1} = 0$ $a_{0\_ms2} = a_{0\_ms2}^{\text{free-fit}} - a_{0\_ms1}^{\text{free-fit}}$ CD a_2	
23				
24				
25				
27				PV LWIR electronic cross-talk
28				
29			Corrected a_0; CD a_2	
30			2003 a_0a_2; $a_{0\_ms1} = 0$	
31	Entire mission MS corrected a_0 CD a_2		a_0 =0 CD a_2	
32				PC LWIR optical cross-talk
33			Early mission: MS corrected a_0 Since 2003: a_0 =0 CD a_2	
34				
35				
36				

Bands 20 and 29 a0 correction and C7 algorithm

- Based on the bias trend derived from the Terra-IASI comparison and qDCC trending, derive the a0 correction for each month
- The a0 correction for C7 LUT and deriving a2 is the yearly sliding window averaged.
- Years 2000-2003 had a few configuration and setting changes. For band 20: use the average a0 correction from 2003-2004 to avoid discontinuity
- For each WUCD event, apply the a0 correction for both mirror sides and derive a2. Use C7 TEB a0 and a2 LUT procedure to generate a0 and a2 LUTs
- The Dome-C, ocean, and desert measurements will also be used as reference to monitor broader BT range

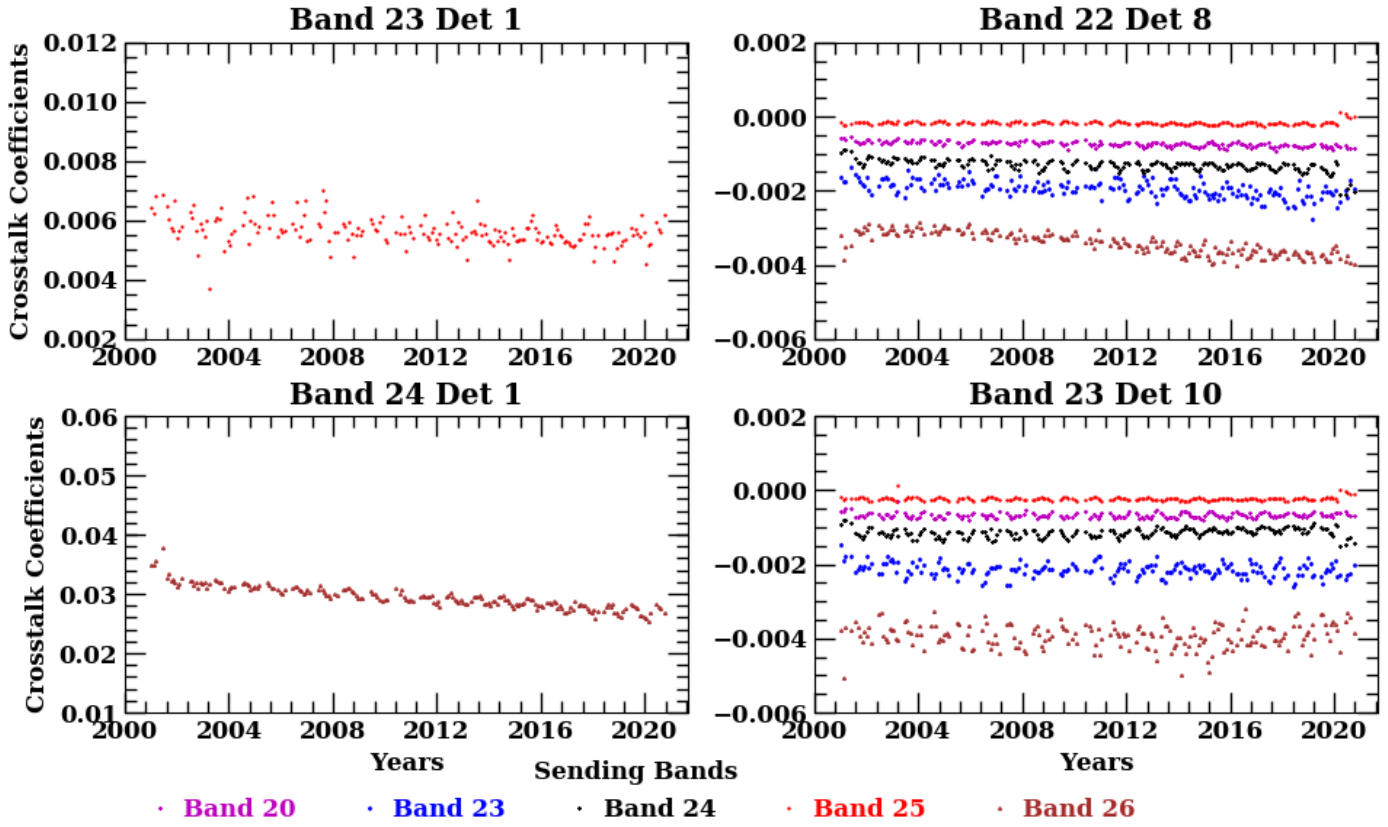




Terra MWIR bands cross-talk corrections

The cross-talk coefficients have been processed for the Terra MWIR bands from 2003 to present. The algorithm is described in the reference.

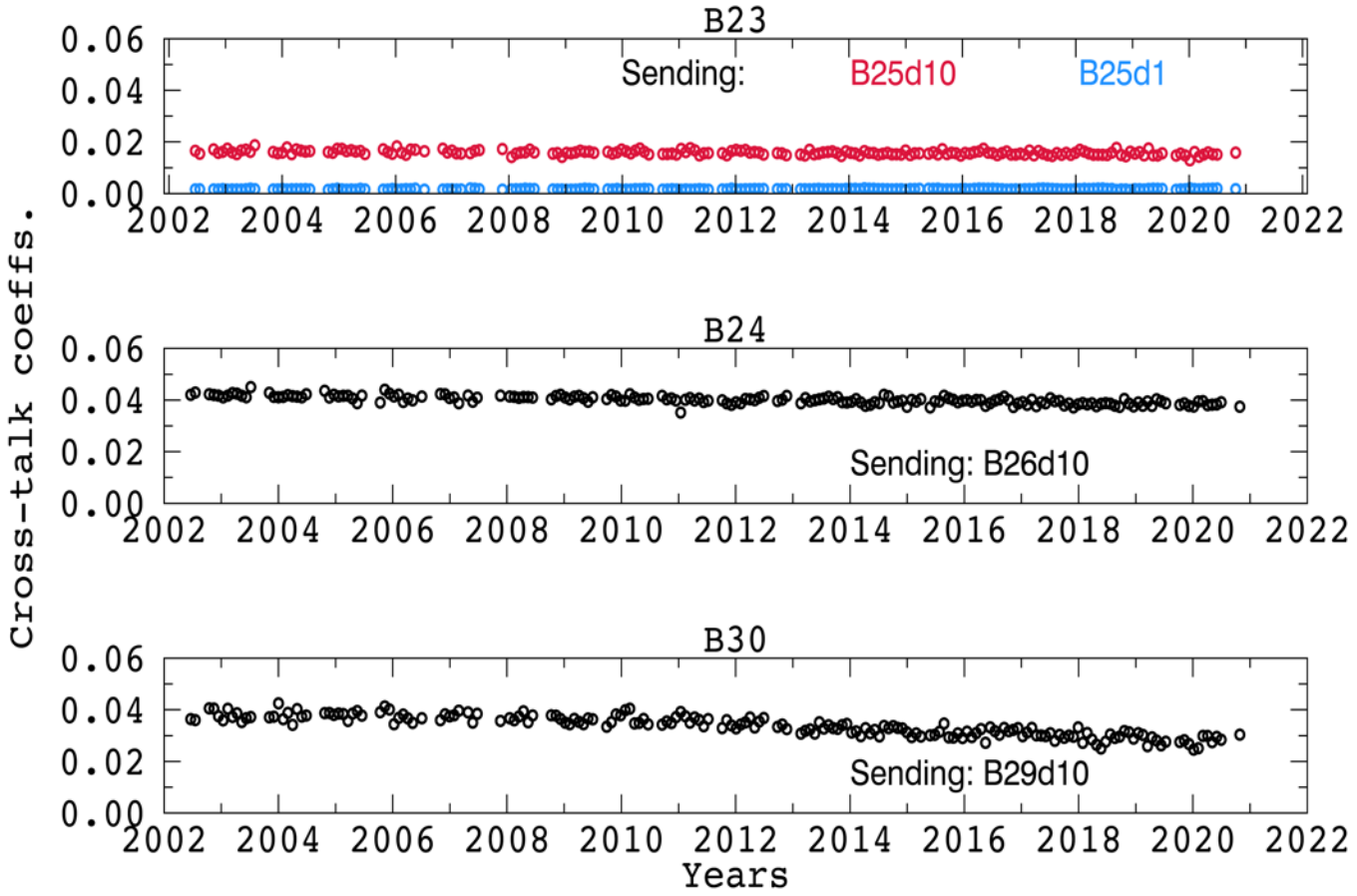
- Band 23 detector 1 cross-talk coefficient from sending band 25 detector 10 is stable
- Band 24 detector 1 cross-talk coefficient from sending band 26 detector 10 shows downward trend
- Band 22 detector 8 and band 23 detector 10 contamination comes from multiple bands. The cross-talk coefficients are stable
- These coefficients will be used in C7 LUTs



Aqua MWIR and LWIR bands cross-talk corrections

Mission-long cross-talk coefficients have been processed for the Aqua MWIR and LWIR bands. An in-depth description of the algorithm can be found in the reference below.

- Bands 20, 22, 23, and 25 detector 1 cross-talk coefficients from sending bands 22, 23, 25, and 24 detector 10, respectively, are quite stable
- Band 24 detector 1 cross-talk coefficient from sending band 26 detector 10 shows a slight downward trend
- Bands 27 (from band 30 detectors 1 and 10) and 30 (from band 29 detector 10) detector 1 have small decreasing trends
- These coefficients will be used for C7 LUTs generation



PC Crosstalk Trending

- Update monthly with lunar event. All the coefficients for each detector are saved.
- The black is for LUT.
- The Terra PC optical cross-talk updated for each scheduled moon data to monitor the PC cross-talk stability for each detector.